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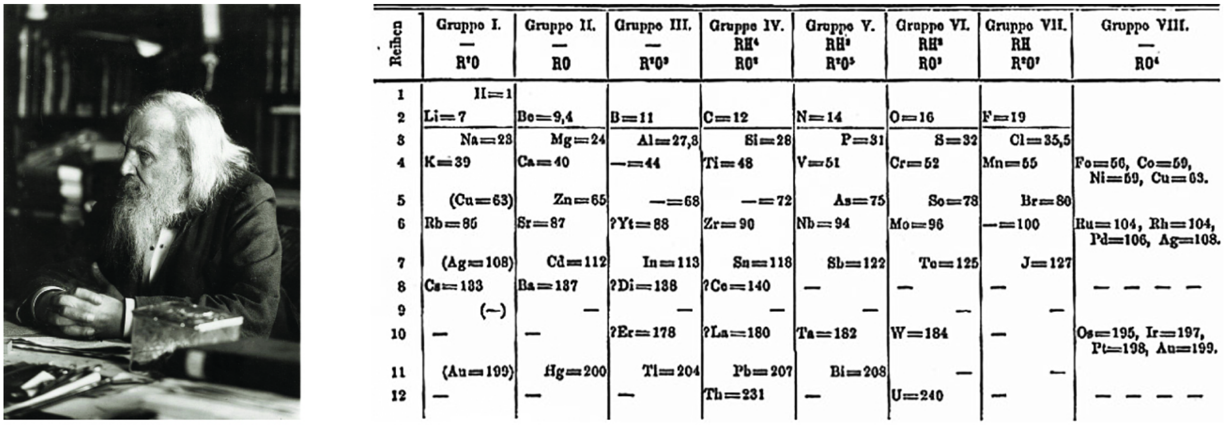
The Periodic Table

By the end of this section, you will be able to:

- State the periodic law and explain the organization of elements in the periodic table
- Predict the general properties of elements based on their location within the periodic table
- Identify metals, nonmetals, and metalloids by their properties and/or location on the periodic table

As early chemists worked to purify ores and discovered more elements, they realized that various elements could be grouped together by their similar chemical behaviors. One such grouping includes lithium (Li), sodium (Na), and potassium (K): These elements all are shiny, conduct heat and electricity well, and have similar chemical properties. A second grouping includes calcium (Ca), strontium (Sr), and barium (Ba), which also are shiny, good conductors of heat and electricity, and have chemical properties in common. However, the specific properties of these two groupings are notably different from each other. For example: Li, Na, and K are much more reactive than are Ca, Sr, and Ba; Li, Na, and K form compounds with oxygen in a ratio of two of their atoms to one oxygen atom, whereas Ca, Sr, and Ba form compounds with one of their atoms to one oxygen atom. Fluorine (F), chlorine (Cl), bromine (Br), and iodine (I) also exhibit similar properties to each other, but these properties are drastically different from those of any of the elements above.

Dimitri Mendeleev in Russia (1869) and Lothar Meyer in Germany (1870) independently recognized that there was a periodic relationship among the properties of the elements known at that time. Both published tables with the elements arranged according to increasing atomic mass. But Mendeleev went one step further than Meyer: He used his table to predict the existence of elements that would have the properties similar to aluminum and silicon, but were yet unknown. The discoveries of gallium (1875) and germanium (1886) provided great support for Mendeleev’s work. Although Mendeleev and Meyer had a long dispute over priority, Mendeleev’s contributions to the development of the periodic table are now more widely recognized ([link]).



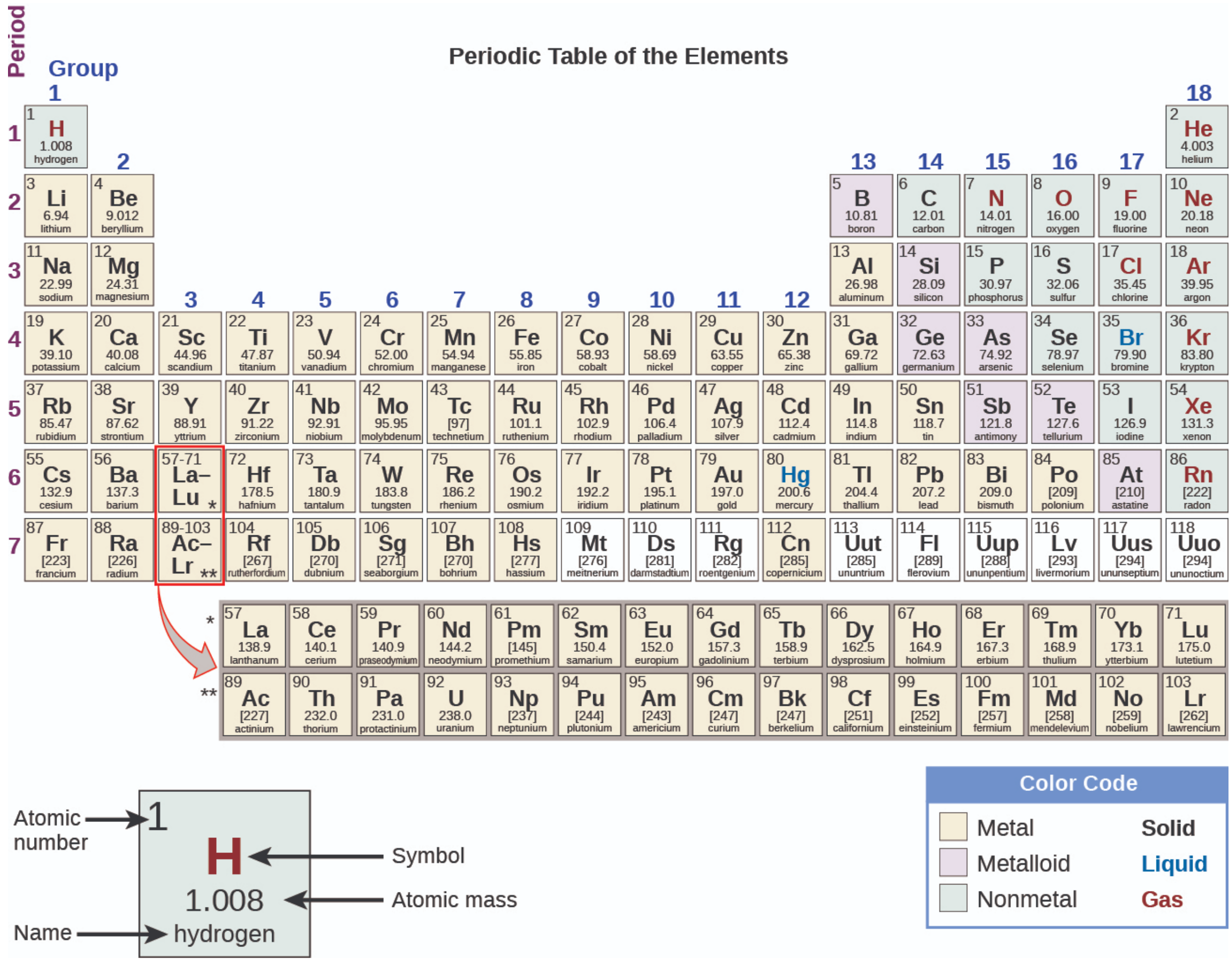
Reihen	Gruppo I. — R^2O	Gruppo II. — RO	Gruppo III. — R^2O^3	Gruppo IV. RH^4 RO^2	Gruppo V. RH^3 R^2O^5	Gruppo VI. RH^2 RO^3	Gruppo VII. RH R^2O^7	Gruppo VIII. — RO^4
1	H=1							
2	Li=7	Be=9,4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27,3	Si=28	P=31	S=32	Cl=35,5	
4	K=39	Ca=40	—=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Co=59, Ni=59, Cu=63.
5	(Cu=63)	Zn=65	—=68	—=72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	—=100	Ru=104, Rh=104, Pd=106, Ag=108.
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140	—	—	—	— — — —
9	(—)	—	—	—	—	—	—	
10	—	—	?Er=178	?La=180	Ta=182	W=184	—	Os=195, Ir=197, Pt=198, Au=199.
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	—	—	
12	—	—	—	Th=231	—	U=240	—	— — — —

(a)

(b)

(a) Dimitri Mendeleev is widely credited with creating (b) the first periodic table of the elements. (credit a: modification of work by Serge Lachinov; credit b: modification of work by “Den fjättrade ankan”/Wikimedia Commons)

By the twentieth century, it became apparent that the periodic relationship involved atomic numbers rather than atomic masses. The modern statement of this relationship, the **periodic law**, is as follows: *the properties of the elements are periodic functions of their atomic numbers*. A modern **periodic table** arranges the elements in increasing order of their atomic numbers and groups atoms with similar properties in the same vertical column ([link]). Each box represents an element and contains its atomic number, symbol, average atomic mass, and (sometimes) name. The elements are arranged in seven horizontal rows, called **periods** or **series**, and 18 vertical columns, called **groups**. Groups are labeled at the top of each column. In the United States, the labels traditionally were numerals with capital letters. However, IUPAC recommends that the numbers 1 through 18 be used, and these labels are more common. For the table to fit on a single page, parts of two of the rows, a total of 14 columns, are usually written below the main body of the table.



Periodic Table of the Elements

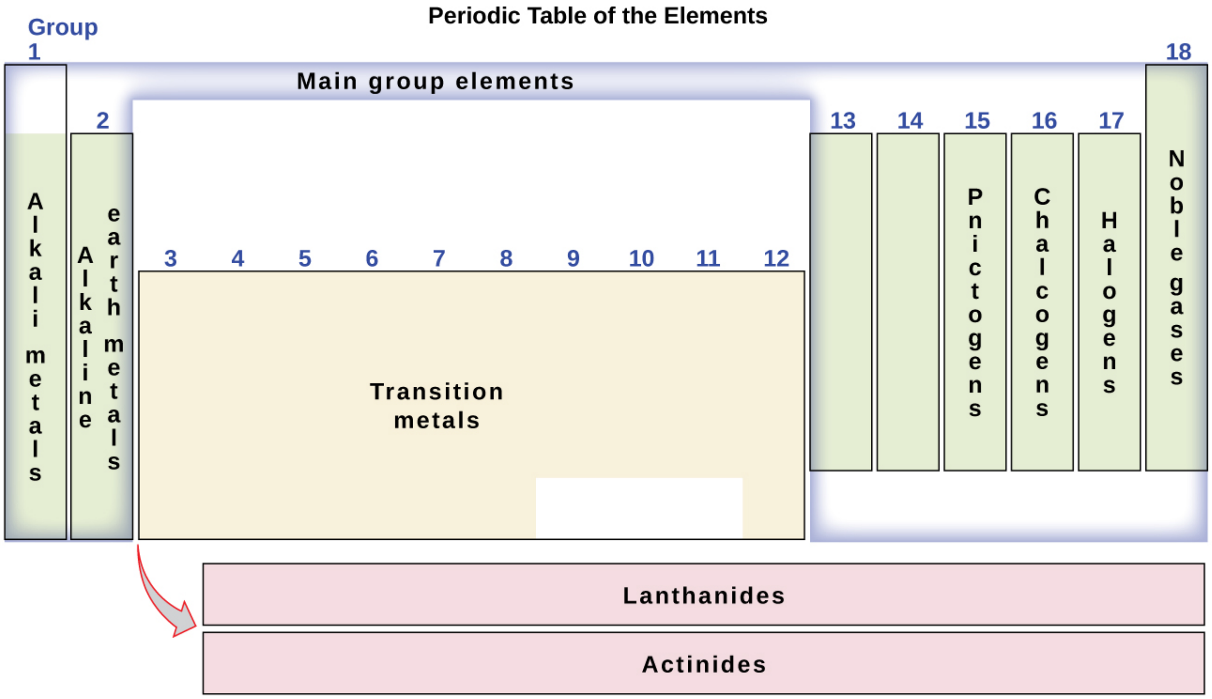
Period \ Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H 1.008 hydrogen																	2 He 4.003 helium
2	3 Li 6.94 lithium	4 Be 9.012 beryllium											5 B 10.81 boron	6 C 12.01 carbon	7 N 14.01 nitrogen	8 O 16.00 oxygen	9 F 19.00 fluorine	10 Ne 20.18 neon
3	11 Na 22.99 sodium	12 Mg 24.31 magnesium											13 Al 26.98 aluminum	14 Si 28.09 silicon	15 P 30.97 phosphorus	16 S 32.06 sulfur	17 Cl 35.45 chlorine	18 Ar 39.95 argon
4	19 K 39.10 potassium	20 Ca 40.08 calcium	21 Sc 44.96 scandium	22 Ti 47.87 titanium	23 V 50.94 vanadium	24 Cr 52.00 chromium	25 Mn 54.94 manganese	26 Fe 55.85 iron	27 Co 58.93 cobalt	28 Ni 58.69 nickel	29 Cu 63.55 copper	30 Zn 65.38 zinc	31 Ga 69.72 gallium	32 Ge 72.63 germanium	33 As 74.92 arsenic	34 Se 78.97 selenium	35 Br 79.90 bromine	36 Kr 83.80 krypton
5	37 Rb 85.47 rubidium	38 Sr 87.62 strontium	39 Y 88.91 yttrium	40 Zr 91.22 zirconium	41 Nb 92.91 niobium	42 Mo 95.95 molybdenum	43 Tc [97] technetium	44 Ru 101.1 ruthenium	45 Rh 102.9 rhodium	46 Pd 106.4 palladium	47 Ag 107.9 silver	48 Cd 112.4 cadmium	49 In 114.8 indium	50 Sn 118.7 tin	51 Sb 121.8 antimony	52 Te 127.6 tellurium	53 I 126.9 iodine	54 Xe 131.3 xenon
6	55 Cs 132.9 cesium	56 Ba 137.3 barium	57-71 La–Lu *	72 Hf 178.5 hafnium	73 Ta 180.9 tantalum	74 W 183.8 tungsten	75 Re 186.2 rhenium	76 Os 190.2 osmium	77 Ir 192.2 iridium	78 Pt 195.1 platinum	79 Au 197.0 gold	80 Hg 200.6 mercury	81 Tl 204.4 thallium	82 Pb 207.2 lead	83 Bi 209.0 bismuth	84 Po [209] polonium	85 At [210] astatine	86 Rn [222] radon
7	87 Fr [223] francium	88 Ra [226] radium	89-103 Ac–Lr **	104 Rf [267] rutherfordium	105 Db [270] dubnium	106 Sg [271] seaborgium	107 Bh [270] bohrium	108 Hs [277] hassium	109 Mt [276] meitnerium	110 Ds [281] darmstadtium	111 Rg [282] roentgenium	112 Cn [285] copernicium	113 Uut [285] ununtrium	114 Fl [289] flerovium	115 Uup [288] ununpentium	116 Lv [293] livermorium	117 Uus [294] ununseptium	118 Uuo [294] ununoctium

*	57 La 138.9 lanthanum	58 Ce 140.1 cerium	59 Pr 140.9 praseodymium	60 Nd 144.2 neodymium	61 Pm [145] promethium	62 Sm 150.4 samarium	63 Eu 152.0 europium	64 Gd 157.3 gadolinium	65 Tb 158.9 terbium	66 Dy 162.5 dysprosium	67 Ho 164.9 holmium	68 Er 167.3 erbium	69 Tm 168.9 thulium	70 Yb 173.1 ytterbium	71 Lu 175.0 lutetium
**	89 Ac [227] actinium	90 Th 232.0 thorium	91 Pa 231.0 protactinium	92 U 238.0 uranium	93 Np [237] neptunium	94 Pu [244] plutonium	95 Am [243] americium	96 Cm [247] curium	97 Bk [247] berkelium	98 Cf [251] californium	99 Es [252] einsteinium	100 Fm [257] fermium	101 Md [258] mendelevium	102 No [259] nobelium	103 Lr [262] lawrencium

Elements in the periodic table are organized according to their properties.

Many elements differ dramatically in their chemical and physical properties, but some elements are similar in their behaviors. For example, many elements appear shiny, are malleable (able to be deformed without breaking) and ductile (can be drawn into wires), and conduct heat and electricity well. Other elements are not shiny, malleable, or ductile, and are poor conductors of heat and electricity. We can sort the elements into large classes with common properties: **metals** (elements that are shiny, malleable, good conductors of heat and electricity—shaded yellow); **nonmetals** (elements that appear dull, poor conductors of heat and electricity—shaded green); and **metalloids** (elements that conduct heat and electricity moderately well, and possess some properties of metals and some properties of nonmetals—shaded purple).

The elements can also be classified into the **main-group elements** (or **representative elements**) in the columns labeled 1, 2, and 13–18; the **transition metals** in the columns labeled 3–12; and **inner transition metals** in the two rows at the bottom of the table (the top-row elements are called **lanthanides** and the bottom-row elements are **actinides**; [link]). The elements can be subdivided further by more specific properties, such as the composition of the compounds they form. For example, the elements in group 1 (the first column) form compounds that consist of one atom of the element and one atom of hydrogen. These elements (except hydrogen) are known as **alkali metals**, and they all have similar chemical properties. The elements in group 2 (the second column) form compounds consisting of one atom of the element and two atoms of hydrogen: These are called **alkaline earth metals**, with similar properties among members of that group. Other groups with specific names are the **pnictogens** (group 15), **chalcogens** (group 16), **halogens** (group 17), and the **noble gases** (group 18, also known as **inert gases**). The groups can also be referred to by the first element of the group: For example, the chalcogens can be called the oxygen group or oxygen family. Hydrogen is a unique, nonmetallic element with properties similar to both group 1 and group 17 elements. For that reason, hydrogen may be shown at the top of both groups, or by itself.



The periodic table organizes elements with similar properties into groups.

Note:

Click on this link for an interactive periodic table, which you can use to explore the properties of the elements (includes podcasts and videos of each element). You may also want to try this one that shows photos of all the elements.

Example:

Naming Groups of Elements

Atoms of each of the following elements are essential for life. Give the group name for the following elements:

(a) chlorine
(b) calcium
(c) sodium
(d) sulfur

Solution

The family names are as follows:

(a) halogen
(b) alkaline earth metal
(c) alkali metal
(d) chalcogen

Check Your Learning

Give the group name for each of the following elements:

(a) krypton
(b) selenium
(c) barium
(d) lithium

Note:

Answer:

(a) noble gas; (b) chalcogen; (c) alkaline earth metal; (d) alkali metal

In studying the periodic table, you might have noticed something about the atomic masses of some of the elements. Element 43 (technetium), element 61 (promethium), and most of the elements with atomic number 84 (polonium) and higher have their atomic mass given in square brackets. This is done for elements that consist entirely of unstable, radioactive isotopes (you will learn more about radioactivity in the nuclear chemistry chapter). An average atomic weight cannot be determined for these elements because their radioisotopes may vary significantly in relative abundance, depending on the source, or may not even exist in nature. The number in square brackets is the atomic mass number (an approximate atomic mass) of the most stable isotope of that element.

Key Concepts and Summary

The discovery of the periodic recurrence of similar properties among the elements led to the formulation of the periodic table, in which the elements are arranged in order of increasing atomic number in rows known as periods and columns known as groups. Elements in the same group of the periodic table have similar chemical properties. Elements can be classified as metals, metalloids, and nonmetals, or as a main-group elements, transition metals, and inner transition metals. Groups are numbered 1–18 from left to right. The elements in group 1 are known as the alkali metals; those in group 2 are the alkaline earth metals; those in 15 are the pnictogens; those in 16 are the chalcogens; those in 17 are the halogens; and those in 18 are the noble gases.

Chemistry End of Chapter Exercises

Exercise:

Problem:

Using the periodic table, classify each of the following elements as a metal or a nonmetal, and then further classify each as a main-group (representative) element, transition metal, or inner transition metal:

(a) uranium

(b) bromine

(c) strontium

(d) neon

(e) gold

(f) americium

(g) rhodium

(h) sulfur

(i) carbon

(j) potassium

Solution:

(a) metal, inner transition metal; (b) nonmetal, representative element; (c) metal, representative element; (d) nonmetal, representative element; (e) metal, transition metal; (f) metal, inner transition metal; (g) metal, transition metal; (h) nonmetal, representative element; (i) nonmetal, representative element; (j) metal, representative element

Exercise:

Problem:

Using the periodic table, classify each of the following elements as a metal or a nonmetal, and then further classify each as a main-group (representative) element, transition metal, or inner transition metal:

(a) cobalt

(b) europium

(c) iodine

(d) indium

(e) lithium

(f) oxygen

(g) cadmium

(h) terbium

(i) rhenium

Exercise:

Problem:

Using the periodic table, identify the lightest member of each of the following groups:

(a) noble gases

(b) alkaline earth metals

(c) alkali metals

(d) chalcogens

Solution:

(a) He; (b) Be; (c) Li; (d) O

Exercise:

Problem:

Using the periodic table, identify the heaviest member of each of the following groups:

(a) alkali metals

(b) chalcogens

(c) noble gases

(d) alkaline earth metals

Exercise:

Problem:

Use the periodic table to give the name and symbol for each of the following elements:

(a) the noble gas in the same period as germanium

(b) the alkaline earth metal in the same period as selenium

(c) the halogen in the same period as lithium

(d) the chalcogen in the same period as cadmium

Solution:

(a) krypton, Kr; (b) calcium, Ca; (c) fluorine, F; (d) tellurium, Te

Exercise:

Problem:

Use the periodic table to give the name and symbol for each of the following elements:

(a) the halogen in the same period as the alkali metal with 11 protons

(b) the alkaline earth metal in the same period with the neutral noble gas with 18 electrons

(c) the noble gas in the same row as an isotope with 30 neutrons and 25 protons

(d) the noble gas in the same period as gold

Exercise:

Problem:

Write a symbol for each of the following neutral isotopes. Include the atomic number and mass number for each.

(a) the alkali metal with 11 protons and a mass number of 23

(b) the noble gas element with 75 neutrons in its nucleus and 54 electrons in the neutral atom

(c) the isotope with 33 protons and 40 neutrons in its nucleus

(d) the alkaline earth metal with 88 electrons and 138 neutrons

Solution:

(a) ${}^{23}_{11}\text{Na}$; (b) ${}^{129}_{54}\text{Xe}$; (c) ${}^{73}_{33}\text{As}$; (d) ${}^{226}_{88}\text{Ra}$

Exercise:

Problem:

Write a symbol for each of the following neutral isotopes. Include the atomic number and mass number for each.

(a) the chalcogen with a mass number of 125

(b) the halogen whose longest-lived isotope is radioactive

(c) the noble gas, used in lighting, with 10 electrons and 10 neutrons

(d) the lightest alkali metal with three neutrons

Glossary

actinide
inner transition metal in the bottom of the bottom two rows of the periodic table

alkali metal
element in group 1

alkaline earth metal
element in group 2

chalcogen

element in group 16

group

vertical column of the periodic table

halogen

element in group 17

inert gas

(also, noble gas) element in group 18

inner transition metal

(also, lanthanide or actinide) element in the bottom two rows; if in the first row, also called lanthanide, or if in the second row, also called actinide

lanthanide

inner transition metal in the top of the bottom two rows of the periodic table

main-group element

(also, representative element) element in columns 1, 2, and 12–18

metal

element that is shiny, malleable, good conductor of heat and electricity

metalloid

element that conducts heat and electricity moderately well, and possesses some properties of metals and some properties of nonmetals

noble gas

(also, inert gas) element in group 18

nonmetal

element that appears dull, poor conductor of heat and electricity

period

(also, series) horizontal row of the periodic table periodic law

properties of the elements are periodic function of their atomic numbers.

periodic table

table of the elements that places elements with similar chemical properties close together

pnictogen

element in group 15

representative element

(also, main-group element) element in columns 1, 2, and 12–18

series

(also, period) horizontal row of the period table

transition metal

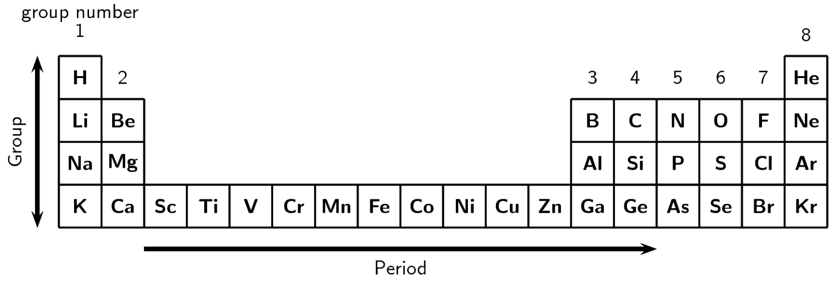
element in columns 3–11

The periodic table: Groups and periods

The arrangement of atoms in the periodic table

The **periodic table of the elements** is a method of showing the chemical elements in a table. The elements are arranged in order of increasing atomic number. Most of the work that was done to arrive at the periodic table that we know, can be attributed to a man called **Dmitri Mendeleev** in 1869. Mendeleev was a Russian chemist who designed the table in such a way that recurring ("periodic") trends in the properties of the elements could be shown. Using the trends he observed, he even left gaps for those elements that he thought were 'missing'. He even predicted the properties that he thought the missing elements would have when they were discovered. Many of these elements were indeed discovered and Mendeleev's predictions were proved to be correct.

To show the recurring properties that he had observed, Mendeleev began new rows in his table so that elements with similar properties were in the same vertical columns, called **groups**. Each row was referred to as a **period**. One important feature to note in the periodic table is that all the non-metals are to the right of the zig-zag line drawn under the element boron. The rest of the elements are metals, with the exception of hydrogen which occurs in the first block of the table despite being a non-metal.



A simplified diagram showing part of the Periodic Table

You can view an online periodic table at Periodic table. The full periodic table is also reproduced at the front of this book.

Activity: Inventing the periodic table

You are the official chemist for the planet Zog. You have discovered all the same elements that we have here on Earth, but you don't have a periodic table. The citizens of Zog want to know how all these elements relate to each other. How would you invent the periodic table? Think about how you would organize the data that you have and what properties you would include. Do not simply copy Mendeleev's ideas, be creative and come up with some of your own. Research other forms of the periodic table and make one that makes sense to you. Present your ideas to your class.

Groups in the periodic table

A *group* is a vertical column in the periodic table and is considered to be the most important way of classifying the elements. If you look at a periodic table, you will see the groups numbered at the top of each column. The groups are numbered from left to right starting with 1 and ending with 18. This is the convention that we will use in this book. On some periodic tables you may see that the groups are numbered from left to right as follows: 1, 2, then an open space which contains the **transition elements**, followed by groups 3 to 8. Another way to label the groups is using Roman numerals. In some groups, the elements display very similar chemical properties and the groups are even given separate names to identify them.

It is worth noting that in each of the groups described above, the **atomic diameter** of the elements increases as you move down the group. This is because, while the number of valence electrons is the same in each element, the number of core electrons increases as one moves down the group.
Khan academy video on the periodic table - 1
[missing_resource: http://www.youtube.com/v/LDHg7Vgzses&rel=0]

Periods in the periodic table

A **period** is a horizontal row in the periodic table of the elements. Some of the trends that can be observed within a period are highlighted below:

- As you move from one group to the next within a period, the number of valence electrons increases by one each time.
- Within a single period, all the valence electrons occur in the same energy shell. If the period increases, so does the energy shell in which the valence electrons occur.
- In general, the diameter of atoms decreases as one moves from left to right across a period. Consider the attractive force between the positively charged nucleus and the negatively charged electrons in an atom. As you move across a period, the number of protons in each atom increases. The number of electrons also increases, but these electrons will still be in the same energy shell. As the number of protons increases, the force of attraction between the nucleus and the electrons will increase and the atomic diameter will decrease.
- Ionisation energy increases as one moves from left to right across a period. As the valence electron shell moves closer to being full, it becomes more difficult to remove electrons. The opposite is true when you move down a *group* in the table because more energy shells are being added. The electrons that are closer to the nucleus 'shield' the outer electrons from the attractive force of the positive nucleus. Because these electrons are not being held to the nucleus as strongly, it is easier for them to be removed and the ionisation energy decreases.
- In general, the reactivity of the elements decreases from left to right across a period.
- The formation of halides follows the general pattern: $\text{X}\,\text{Cl}_\text{n}$ (where X is any element in a specific group and n is the number of that specific group.). For example, the formula for the halides of group 1 will be $\text{X}\,\text{Cl}$, for the second group the halides have the formula $\text{X}\,\text{Cl}_2$ and in the third group the halides have the formula $\text{X}\,\text{Cl}_3$. This should be easy to see if you remember the valency of the group and of the halides.

The formation of oxides show a trend as you move across a period. This should be easy to see if you think about valency. In the first group all the elements lose an electron to form a cation. So the formula for an oxide will be X_2O. In the second group (moving from left to right across a period) the oxides have the formula XO. In the third group the oxides have the formula X_2O_3.

Several other trends may be observed across a period such as density, melting points and boiling points. These trends are not as obvious to see as the above trends and often show variations to the general trend.

Electron affinity and electronegativity also show some general trends across periods. Electron affinity can be thought of as how much an element wants electrons. Electron affinity generally increases from left to right across a period. Electronegativity is the tendency of atoms to attract electrons. The higher the electronegativity, the greater the atom attracts electrons. Electronegativity generally increases across a period (from left to right). Electronegativity and electron affinity will be covered in more detail in a later grade.

You may see periodic tables labeled with s-block, p-block, d-block and f-block. This is simply another way to group the elements. When we group elements like this we are simply noting which orbitals are being filled in each block. This method of grouping is not very useful to the work covered at this level.

Using the properties of the groups and the trends that we observe in certain properties (ionization energy, formation of halides and oxides, melting and boiling points, atomic diameter) we can predict the the properties of unknown elements. For example, the properties of the unfamiliar elements Francium (Fr), Barium (Ba), Astatine (At), and Xenon (Xe) can be predicted by knowing their position on the periodic table. Using the periodic table we can say: Francium (Group 1) is an alkali metal, very reactive and needs to lose 1 electron to obtain a full outer energy shell; Barium (Group 2) is an alkali earth metal and needs to lose 2 electrons to achieve stability; Astatine (Group 7) is a halogen, very reactive and needs to gain 1 electron to obtain a full outer energy shell; and Xenon (Group 8) is a noble gas and thus stable due to its full outer energy shell. This is how scientists are able to say what sort of properties the atoms in the last period have. Almost all of the elements in this period do not occur naturally on earth and are made in laboratories. These atoms do not exist for very long (they are very unstable and break apart easily) and so measuring their properties is difficult.

Exercise: Elements in the periodic table

Refer to the elements listed below:

- Lithium (Li)
- Chlorine (Cl)
- Magnesium (Mg)
- Neon (Ne)
- Oxygen (O)
- Calcium (Ca)
- Carbon (C)

Which of the elements listed above:

1. belongs to Group 1
2. is a halogen
3. is a noble gas
4. is an alkali metal
5. has an atomic number of 12
6. has 4 neutrons in the nucleus of its atoms
7. contains electrons in the 4th energy level
8. has only one valence electron
9. has all its energy orbitals full
10. will have chemical properties that are most similar
11. will form positive ions

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Nuclear Radioactivity

LEARNING OBJECTIVES

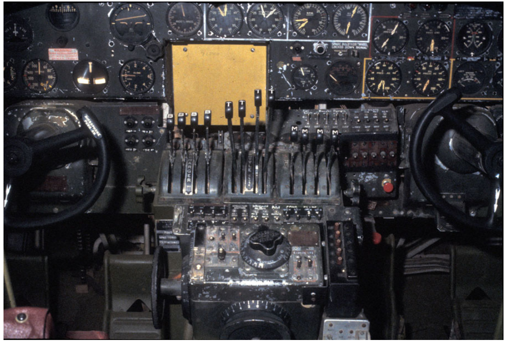
By the end of this section, you will be able to:

- Explain nuclear radiation.
- Explain the types of radiation – alpha emission, beta emission, and gamma emission.
- Explain the ionization of radiation in an atom.
- Define the range of radiation.

The information presented in this section supports the following AP® learning objectives and science practices:

- **5.B.8.1** The student is able to describe emission or absorption spectra associated with electronic or nuclear transitions as transitions between allowed energy states of the atom in terms of the principle of energy conservation, including characterization of the frequency of radiation emitted or absorbed. **(S.P. 1.2, 7.2)**
- **5.C.1.1** The student is able to analyze electric charge conservation for nuclear and elementary particle reactions and make predictions related to such reactions based upon conservation of charge. **(S.P. 6.4, 7.2)**

The discovery and study of nuclear radioactivity quickly revealed evidence of revolutionary new physics. In addition, uses for nuclear radiation also emerged quickly—for example, people such as Ernest Rutherford used it to determine the size of the nucleus and devices were painted with radon-doped paint to make them glow in the dark (see [link]). We therefore begin our study of nuclear physics with the discovery and basic features of nuclear radioactivity.



The dials of this World War II aircraft glow in the dark, because they are painted with radium-doped phosphorescent paint. It is a poignant reminder of the dual nature of radiation. Although radium paint dials are conveniently visible day and night, they emit radon, a radioactive gas that is hazardous and is not directly sensed. (credit: U.S. Air Force Photo)

Discovery of Nuclear Radioactivity

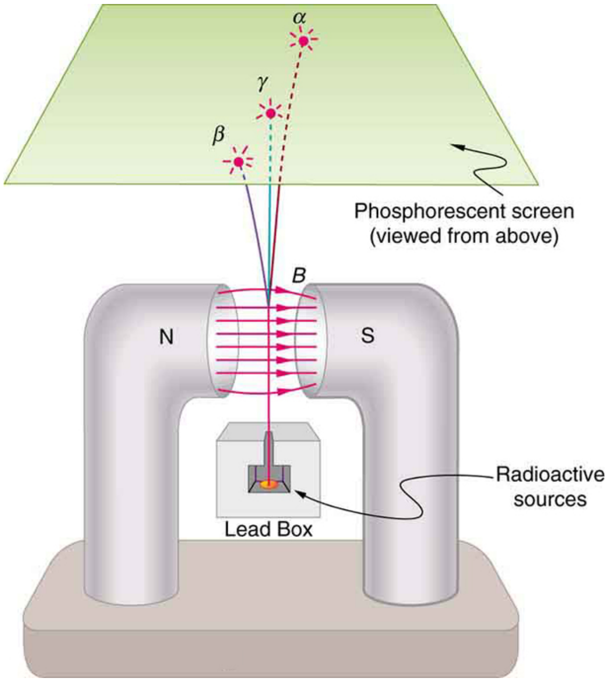
In 1896, the French physicist Antoine Henri Becquerel (1852–1908) accidentally found that a uranium-rich mineral called pitchblende emits invisible, penetrating rays that can darken a photographic plate enclosed in an opaque envelope. The rays therefore carry energy; but amazingly, the pitchblende emits them continuously without any energy input. This is an apparent violation of the law of conservation of energy, one that we now understand is due to the conversion of a small amount of mass into energy, as related in Einstein’s famous equation $E = mc^2$. It was soon evident that Becquerel’s rays originate in the nuclei of the atoms and have other unique characteristics. The emission of these rays is called **nuclear radioactivity** or simply **radioactivity**. The rays themselves are called **nuclear radiation**. A nucleus that spontaneously destroys part of its mass to emit radiation is said to **decay** (a term also used to describe the emission of radiation by atoms in excited states). A substance or object that emits nuclear radiation is said to be **radioactive**.

Two types of experimental evidence imply that Becquerel’s rays originate deep in the heart (or nucleus) of an atom. First, the radiation is found to be associated with certain elements, such as uranium. Radiation does not vary with chemical state—that is, uranium is radioactive whether it is in the form of an element or compound. In addition, radiation does not vary with temperature, pressure, or ionization state of the uranium atom. Since all of these factors affect electrons in an atom, the radiation cannot come from electron transitions, as atomic spectra do. The huge energy emitted during each event is the second piece of evidence that the radiation cannot be atomic. Nuclear radiation has energies of the order of 10^6 eV per event, which is much greater than the typical atomic energies (a few eV), such as that observed in spectra and chemical reactions, and more than ten times as high as the most energetic characteristic x rays. Becquerel did not vigorously pursue his discovery for very long. In 1898, Marie Curie (1867–1934), then a graduate student married the already well-known French physicist Pierre Curie (1859–1906), began her doctoral study of Becquerel’s rays. She and her husband soon discovered two new radioactive elements, which she named *polonium* (after her native land) and *radium* (because it radiates). These two new elements filled holes in the periodic table and, further, displayed much higher levels of radioactivity per gram of material than uranium. Over a period of four years, working under poor conditions and spending their own funds, the Curies processed more than a ton of uranium ore to isolate a gram of radium salt. Radium became highly sought after, because it was about two million times as radioactive as uranium.

Curie’s radium salt glowed visibly from the radiation that took its toll on them and other unaware researchers. Shortly after completing her Ph.D., both Curies and Becquerel shared the 1903 Nobel Prize in physics for their work on radioactivity. Pierre was killed in a horse cart accident in 1906, but Marie continued her study of radioactivity for nearly 30 more years. Awarded the 1911 Nobel Prize in chemistry for her discovery of two new elements, she remains the only person to win Nobel Prizes in physics and chemistry. Marie’s radioactive fingerprints on some pages of her notebooks can still expose film, and she suffered from radiation-induced lesions. She died of leukemia likely caused by radiation, but she was active in research almost until her death in 1934. The following year, her daughter and son-in-law, Irene and Frederic Joliot-Curie, were awarded the Nobel Prize in chemistry for their discovery of artificially induced radiation, adding to a remarkable family legacy.

Alpha, Beta, and Gamma

Research begun by people such as New Zealander Ernest Rutherford soon after the discovery of nuclear radiation indicated that different types of rays are emitted. Eventually, three types were distinguished and named **alpha** (α), **beta**(β), and **gamma**(γ), because, like x-rays, their identities were initially unknown. [link] shows what happens if the rays are passed through a magnetic field. The γs are unaffected, while the α s and β s are deflected in opposite directions, indicating the α s are positive, the β s negative, and the γ s uncharged. Rutherford used both magnetic and electric fields to show that α s have a positive charge twice the magnitude of an electron, or $+2 \mid q_e \mid$. In the process, he found the α s charge to mass ratio to be several thousand times smaller than the electron’s. Later on, Rutherford collected α s from a radioactive source and passed an electric discharge through them, obtaining the spectrum of recently discovered helium gas. Among many important discoveries made by Rutherford and his collaborators was the proof that α *radiation is the emission of a helium nucleus*. Rutherford won the Nobel Prize in chemistry in 1908 for his early work. He continued to make important contributions until his death in 1934.



Alpha, beta, and gamma rays are passed through a magnetic field on the way to a phosphorescent screen. The α s and β s bend in opposite directions, while the γ s are unaffected, indicating a positive charge for α s, negative for β s, and neutral for γ s. Consistent results are obtained with electric fields. Collection of the radiation offers further confirmation from the direct measurement of excess charge.

Other researchers had already proved that β s are negative and have the same mass and same charge-to-mass ratio as the recently discovered electron. By 1902, it was recognized that β *radiation is the emission of an electron*. Although β s are electrons, they do not exist in the nucleus before it decays and are not ejected atomic electrons—the electron is created in the nucleus at the instant of decay.

Since γ s remain unaffected by electric and magnetic fields, it is natural to think they might be photons. Evidence for this grew, but it was not until 1914 that this was proved by Rutherford and collaborators. By scattering γ radiation from a crystal and observing interference, they demonstrated that γ *radiation is the emission of a high-energy photon by a nucleus*. In fact, γ radiation comes from the de-excitation of a nucleus, just as an x ray comes from the de-excitation of an atom. The names "γ ray" and "x ray" identify the source of the radiation. At the same energy, γ rays and x rays are otherwise identical.

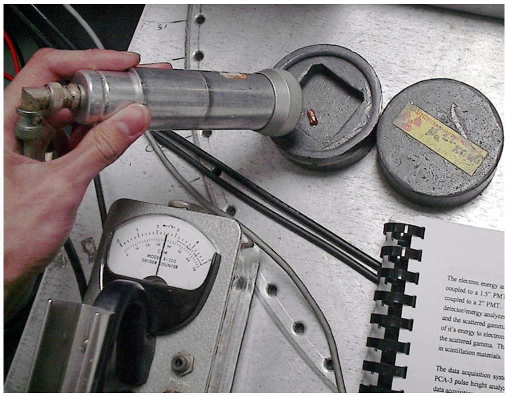
Type of Radiation	**Range**
α -Particles	A sheet of paper, a few cm of air, fractions of a mm of tissue
β -Particles	A thin aluminum plate, or tens of cm of tissue
γ Rays	Several cm of lead or meters of concrete

Properties of Nuclear Radiation

Ionization and Range

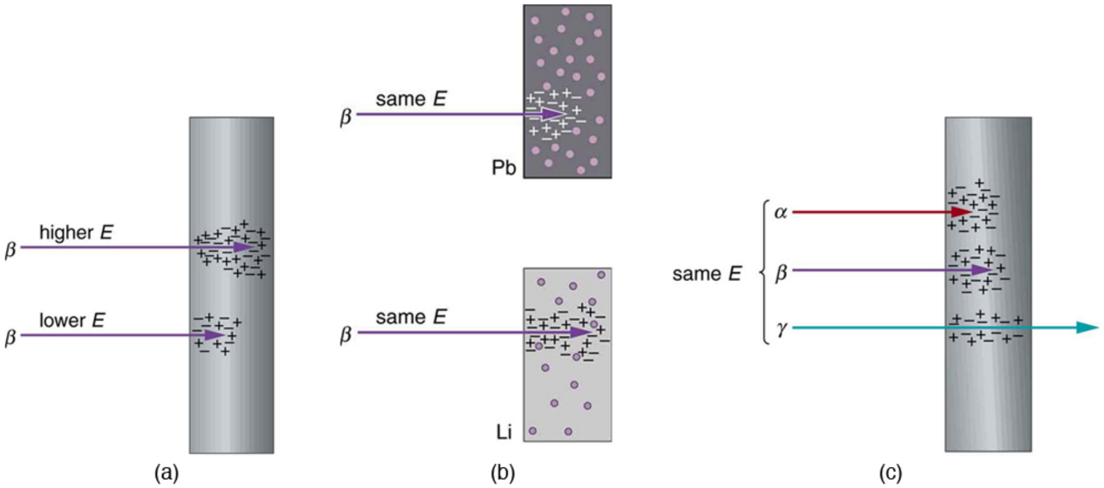
Two of the most important characteristics of α, β, and γ rays were recognized very early. All three types of nuclear radiation produce *ionization* in materials, but they penetrate different distances in materials—that is, they have different *ranges*. Let us examine why they have these characteristics and what are some of the consequences.

Like x rays, nuclear radiation in the form of α s, β s, and γ s has enough energy per event to ionize atoms and molecules in any material. The energy emitted in various nuclear decays ranges from a few keV to more than 10 MeV, while only a few eV are needed to produce ionization. The effects of x rays and nuclear radiation on biological tissues and other materials, such as solid state electronics, are directly related to the ionization they produce. All of them, for example, can damage electronics or kill cancer cells. In addition, methods for detecting x rays and nuclear radiation are based on ionization, directly or indirectly. All of them can ionize the air between the plates of a capacitor, for example, causing it to discharge. This is the basis of inexpensive personal radiation monitors, such as pictured in [link]. Apart from α, β, and γ, there are other forms of nuclear radiation as well, and these also produce ionization with similar effects. We define **ionizing radiation** as any form of radiation that produces ionization whether nuclear in origin or not, since the effects and detection of the radiation are related to ionization.



These dosimeters (literally, dose meters) are personal radiation monitors that detect the amount of radiation by the discharge of a rechargeable internal capacitor. The amount of discharge is related to the amount of ionizing radiation encountered, a measurement of dose. One dosimeter is shown in the charger. Its scale is read through an eyepiece on the top. (credit: L. Chang, Wikimedia Commons)

The **range of radiation** is defined to be the distance it can travel through a material. Range is related to several factors, including the energy of the radiation, the material encountered, and the type of radiation (see [link]). The higher the *energy*, the greater the range, all other factors being the same. This makes good sense, since radiation loses its energy in materials primarily by producing ionization in them, and each ionization of an atom or a molecule requires energy that is removed from the radiation. The amount of ionization is, thus, directly proportional to the energy of the particle of radiation, as is its range.



The penetration or range of radiation depends on its energy, the material it encounters, and the type of radiation. (a) Greater energy means greater range. (b) Radiation has a smaller range in materials with high electron density. (c) Alphas have the smallest range, betas have a greater range, and gammas penetrate the farthest.

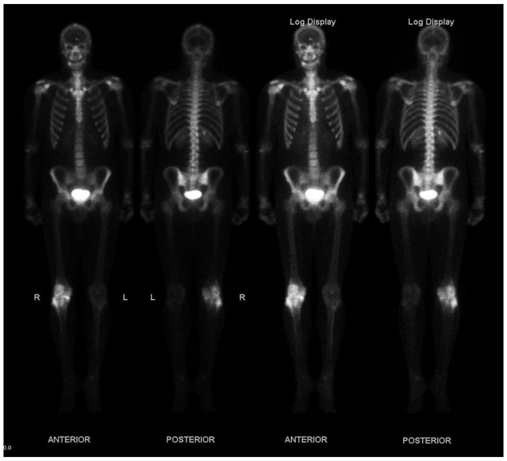
Radiation can be absorbed or shielded by materials, such as the lead aprons dentists drape on us when taking x rays. Lead is a particularly effective shield compared with other materials, such as plastic or air. How does the range of radiation depend on *material*? Ionizing radiation interacts best with charged particles in a material. Since electrons have small masses, they most readily absorb the energy of the radiation in collisions. The greater the density of a material and, in particular, the greater the density of electrons within a material, the smaller the range of radiation.

Note:
Collisions
Conservation of energy and momentum often results in energy transfer to a less massive object in a collision. This was discussed in detail in Work, Energy, and Energy Resources, for example.

Different *types* of radiation have different ranges when compared at the same energy and in the same material. Alphas have the shortest range, betas penetrate farther, and gammas have the greatest range. This is directly related to charge and speed of the particle or type of radiation. At a given energy, each α, β, or γ will produce the same number of ionizations in a material (each ionization requires a certain amount of energy on average). The more readily the particle produces ionization, the more quickly it will lose its energy. The effect of *charge* is as follows: The α has a charge of $+2q_e$, the β has a charge of $-q_e$, and the γ is uncharged. The electromagnetic force exerted by the α is thus twice as strong as that exerted by the β and it is more likely to produce ionization. Although chargeless, the γ does interact weakly because it is an electromagnetic wave, but it is less likely to produce ionization in any encounter. More quantitatively, the change in momentum Δp given to a particle in the material is $\Delta p = F\Delta t$, where F is the force the α, β, or γ exerts over a time Δt. The smaller the charge, the smaller is F and the smaller is the momentum (and energy) lost. Since the speed of alphas is about 5% to 10% of the speed of light, classical (non-relativistic) formulas apply.

The *speed* at which they travel is the other major factor affecting the range of α s, β s, and γ s. The faster they move, the less time they spend in the vicinity of an atom or a molecule, and the less likely they are to interact. Since α s and β s are particles with mass (helium nuclei and electrons, respectively), their energy is kinetic, given classically by $\frac{1}{2}mv^2$. The mass of the β particle is thousands of times less than that of the α s, so that β s must travel much faster than α s to have the same energy. Since β s move faster (most at relativistic speeds), they have less time to interact than α s. Gamma rays are photons, which must travel at the speed of light. They are even less likely to interact than a β, since they spend even less time near a given atom (and they have no charge). The range of γ s is thus greater than the range of β s.

Alpha radiation from radioactive sources has a range much less than a millimeter of biological tissues, usually not enough to even penetrate the dead layers of our skin. On the other hand, the same α radiation can penetrate a few centimeters of air, so mere distance from a source prevents α radiation from reaching us. This makes α radiation relatively safe for our body compared to β and γ radiation. Typical β radiation can penetrate a few millimeters of tissue or about a meter of air. Beta radiation is thus hazardous even when not ingested. The range of β s in lead is about a millimeter, and so it is easy to store β sources in lead radiation-proof containers. Gamma rays have a much greater range than either αs or βs. In fact, if a given thickness of material, like a lead brick, absorbs 90% of the γs, then a second lead brick will only absorb 90% of what got through the first. Thus, γs do not have a well-defined range; we can only cut down the amount that gets through. Typically, γs can penetrate many meters of air, go right through our bodies, and are effectively shielded (that is, reduced in intensity to acceptable levels) by many centimeters of lead. One benefit of γs is that they can be used as radioactive tracers (see [link]).



This image of the concentration of a radioactive tracer in a patient’s body reveals where the most active bone cells are, an indication of bone cancer. A short-lived radioactive substance that locates itself selectively is given to the patient, and the radiation is measured with an external detector. The emitted γ radiation has a sufficient range to leave the body—the range of α s and β s is too small for them to be observed outside the patient. (credit: Kieran Maher, Wikimedia Commons)

Note:

PhET Explorations: Beta Decay

Watch beta decay occur for a collection of nuclei or for an individual nucleus.

Beta Decay

Test Prep for AP Courses

Exercise:

Problem:

A nucleus is observed to emit a γ ray with a frequency of 6.3×10^{19} Hz. What must happen to the nucleus as a consequence?

a. The nucleus must gain 0.26 MeV.
b. The nucleus must also emit an α particle of energy 0.26 MeV in the opposite direction.
c. The nucleus must lose 0.26 MeV.
d. The nucleus must also emit a β particle of energy 0.26 MeV in the opposite direction.

Solution:

(c)

Exercise:

Problem:

A uranium nucleus emits an α particle. Assuming charge is conserved, the resulting nucleus must be

a. thorium
b. plutonium
c. radium
d. curium

Section Summary

- Some nuclei are radioactive—they spontaneously decay destroying some part of their mass and emitting energetic rays, a process called nuclear radioactivity.
- Nuclear radiation, like x rays, is ionizing radiation, because energy sufficient to ionize matter is emitted in each decay.
- The range (or distance traveled in a material) of ionizing radiation is directly related to the charge of the emitted particle and its energy, with greater-charge and lower-energy particles having the shortest ranges.
- Radiation detectors are based directly or indirectly upon the ionization created by radiation, as are the effects of radiation on living and inert materials.

Conceptual Questions

Exercise:

Problem:

Suppose the range for $5.0 \text{ MeV}\alpha$ ray is known to be 2.0 mm in a certain material. Does this mean that every $5.0 \text{ MeV}\alpha$ a ray that strikes this material travels 2.0 mm, or does the range have an average value with some statistical fluctuations in the distances traveled? Explain.

Exercise:

Problem:

What is the difference between γ rays and characteristic x rays? Is either necessarily more energetic than the other? Which can be the most energetic?

Exercise:

Problem:

Ionizing radiation interacts with matter by scattering from electrons and nuclei in the substance. Based on the law of conservation of momentum and energy, explain why electrons tend to absorb more energy than nuclei in these interactions.

Exercise:

Problem:

What characteristics of radioactivity show it to be nuclear in origin and not atomic?

Exercise:

Problem:

What is the source of the energy emitted in radioactive decay? Identify an earlier conservation law, and describe how it was modified to take such processes into account.

Exercise:

Problem:

Consider [link]. If an electric field is substituted for the magnetic field with positive charge instead of the north pole and negative charge instead of the south pole, in which directions will the α, β , and γ rays bend?

Exercise:

Problem:

Explain how an α particle can have a larger range in air than a β particle with the same energy in lead.

Exercise:

Problem:

Arrange the following according to their ability to act as radiation shields, with the best first and worst last. Explain your ordering in terms of how radiation loses its energy in matter.

(a) A solid material with low density composed of low-mass atoms.

(b) A gas composed of high-mass atoms.

(c) A gas composed of low-mass atoms.

(d) A solid with high density composed of high-mass atoms.

Exercise:

Problem:

Often, when people have to work around radioactive materials spills, we see them wearing white coveralls (usually a plastic material). What types of radiation (if any) do you think these suits protect the worker from, and how?

Glossary

alpha rays
one of the types of rays emitted from the nucleus of an atom

beta rays
one of the types of rays emitted from the nucleus of an atom

gamma rays
one of the types of rays emitted from the nucleus of an atom

ionizing radiation
radiation (whether nuclear in origin or not) that produces ionization whether nuclear in origin or not

nuclear radiation
rays that originate in the nuclei of atoms, the first examples of which were discovered by Becquerel

radioactivity
the emission of rays from the nuclei of atoms

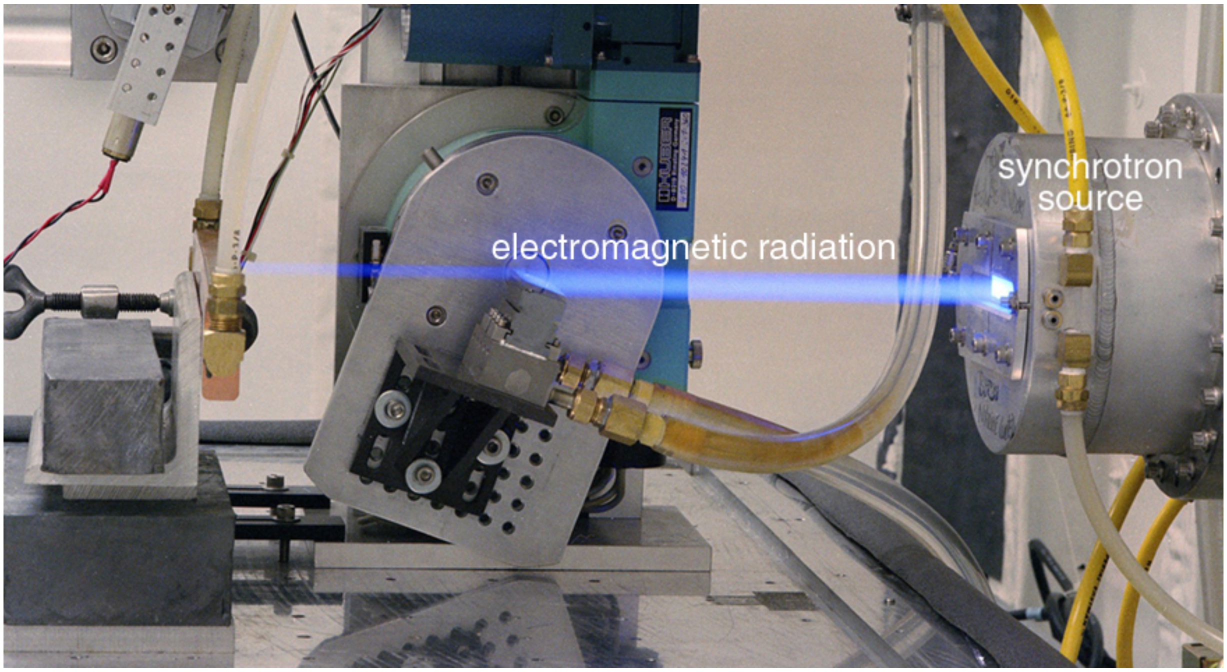
radioactive
a substance or object that emits nuclear radiation

range of radiation
the distance that the radiation can travel through a material

Connection for AP® Courses class="introduction"

- Define radioactivity.

The synchrotron source produces electromagnetic radiation, as evident from the visible glow. (credit: United States Department of Energy, via Wikimedia Commons)



In this chapter, students will explore radioactivity and nuclear physics. Students will learn about the structure and properties of a nucleus (Enduring Understanding 1.A, Essential Knowledge 1.A.3), supporting Big Idea 1. Students will also study the forces that govern the behavior of the nucleus, including the weak force and the strong force (Enduring Understanding 3.G). This supports Big Idea 3 by explaining that interactions can be described by forces, such as the strong force between nucleons holding the nucleus together.

Students will also learn the conservation laws associated with nuclear physics, such as conservation of energy (Enduring Understanding 5.B), conservation of charge (Enduring Understanding 5.C) and conservation of nucleon number (Enduring Understanding 5.G). Students will study the processes that can be described using conservation laws (Big Idea 5), such as radioactive decay, nuclear absorption and emission of nuclear energy, usually regulated by photons (Essential Knowledge 5.B.8). As part of the study of conservation laws, students will explore the consequences of charge conservation (Essential Knowledge 5.C.1) during radioactive decay and during interactions between nuclei (Essential Knowledge 5.C.2). Students will also learn how conservation of nucleon number determines which nuclear reactions can occur (Essential Knowledge 5.G.1). Students will also study types of nuclear radiation, radioactivity, and the binding energy of a nucleus.

This chapter also supports Big Idea 7 by exploring how probability can describe the behavior of quantum mechanical systems. Students will study the process of radioactive decay, which can be described by probability theory. Students will also explore examples demonstrating spontaneous radioactive decay as a probabilistic statistical process (Essential Knowledge 7.C.3), thus making a connection between modeling matter with a wave function and probabilistic description of the microscopic world (Enduring Understanding 7.C).

The content in this chapter supports:

Big Idea 1 Objects and systems have properties such as mass and charge. Systems may have internal structure.

Enduring Understanding 1.A The internal structure of a system determines many properties of the system.

Essential Knowledge 1.A.3 Nuclei have internal structures that determine their properties.

Big Idea 3 The interactions of an object with other objects can be described by forces.

Enduring Understanding 3.G Certain types of forces are considered fundamental.

Essential Knowledge 3.G.3 The strong force is exerted at nuclear scales and dominates the interactions of nucleons.

Big Idea 5 Changes that occur as a result of interactions are constrained by conservation laws.

Enduring Understanding 5.B The energy of a system is conserved.

Essential Knowledge 5.B.8 Energy transfer occurs when photons are absorbed or emitted, for example, by atoms or nuclei.

Enduring Understanding 5.C The electric charge of a system is conserved.

Essential Knowledge 5.C.1 Electric charge is conserved in nuclear and elementary particle reactions, even when elementary particles are produced or destroyed. Examples should include equations representing nuclear decay.

Essential Knowledge 5.C.2 The exchange of electric charges among a set of objects in a system conserves electric charge.

Enduring Understanding 5.G Nucleon number is conserved.

Essential Knowledge 5.G.1 The possible nuclear reactions are constrained by the law of conservation of nucleon number.

Big Idea 7 The mathematics of probability can be used to describe the behavior of complex systems and to interpret the behavior of quantum mechanical systems.

Enduring Understanding 7.C At the quantum scale, matter is described by a wave function, which leads to a probabilistic description of the microscopic world.

Essential Knowledge 7.C.3 The spontaneous radioactive decay of an individual nucleus is described by probability.

Slavery, Violence, and Exploitation in 19th-Century U.S. Literature
This module considers strategies for teaching George Dunham's travel journal A Journey to Brazil in conjunction with U.S. anti-slavery literature.

Slavery, Violence, and Exploitation in 19th-Century U.S. Literature

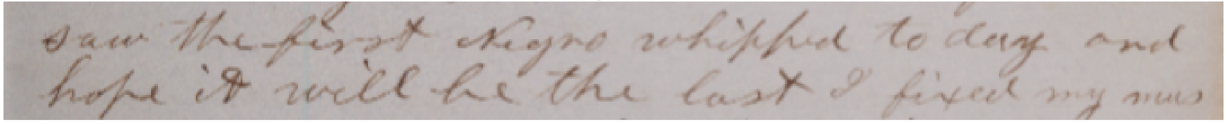
As sectional tensions within the U.S. escalated toward civil war, African slavery became an increasingly important point of focus for literary texts of the antebellum period. Anti-slavery ideologies feature prominently in works by several canonical authors of the time, including essays by Ralph Waldo Emerson, “The Fugitive Slave Law,” (1851) and Henry David Thoreau, “Civil Disobedience,” (1849) as well as Herman Melville’s renowned novella, "Benito Cereno" (1856). Though a long-standing genre throughout the Americas, the slave narrative reached its peak of popularity during the ten years leading up to the U.S. Civil War, its most famous iterations now being Frederick Douglass’s *Narrative of the Life* (1845) and Harriet Jacobs’ *Incidents in the Life of a Slave Girl* (1861). And the most popular U.S. novel of the entire nineteenth century was, of course, Harriet Beecher Stowe’s *Uncle Tom’s Cabin* (1852). This brief catalogue does not even begin to account for the plethora of pro-slavery texts that appeared in the years following the publication of *Uncle Tom’s Cabin*, often referred to as “anti-Tom novels.” Some notable examples of these anti-Tom novels include *The Planter’s Northern Bride* (1854) by Caroline Lee Hentz and *The Free Flag of Cuba* (1854) by Lucy Holcombe Pickens. Even as these works waged a fierce ideological battle, they shared a common underlying goal in purporting to depict the realities of the slave system in America. While anti-slavery texts highlighted the violence and degradation experienced by slaves within the South, pro-slavery writers countered with images of loyal and happy slaves who depended upon their owners for their own well-being and protection. These debates were no doubt at the front of George Dunham’s mind as he recorded his observations of the Brazilian slave system and its everyday operations.

Positioning Dunham’s experiences with Brazilian slavery in his *[missing_resource: http://hdl.handle.net/1911/9247]* (1853) - which is held at Rice University's Woodson Research Center as part of the larger [missing_resource: http://oaap.rice.edu/]

A Journey to Brazil, 1853

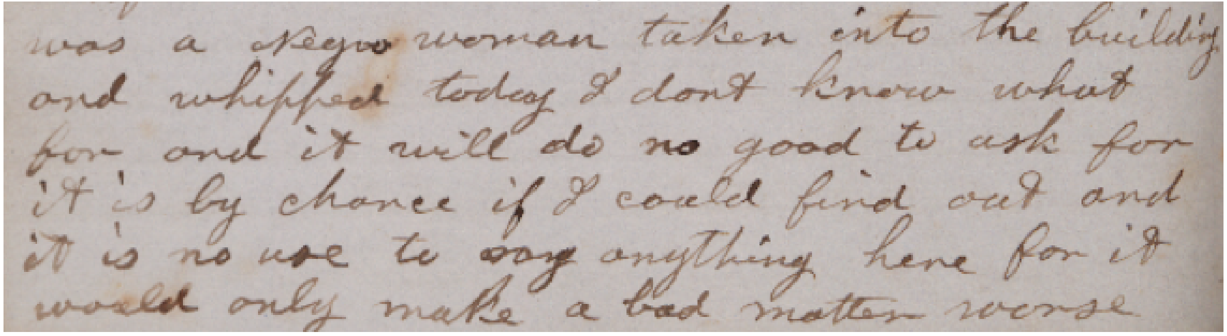
Excerpts from the original manuscript of George Dunham's travel journal.

Page 49



saw the first Negro whipped to day and
hope it will be the last I fixed my mus

Page 98



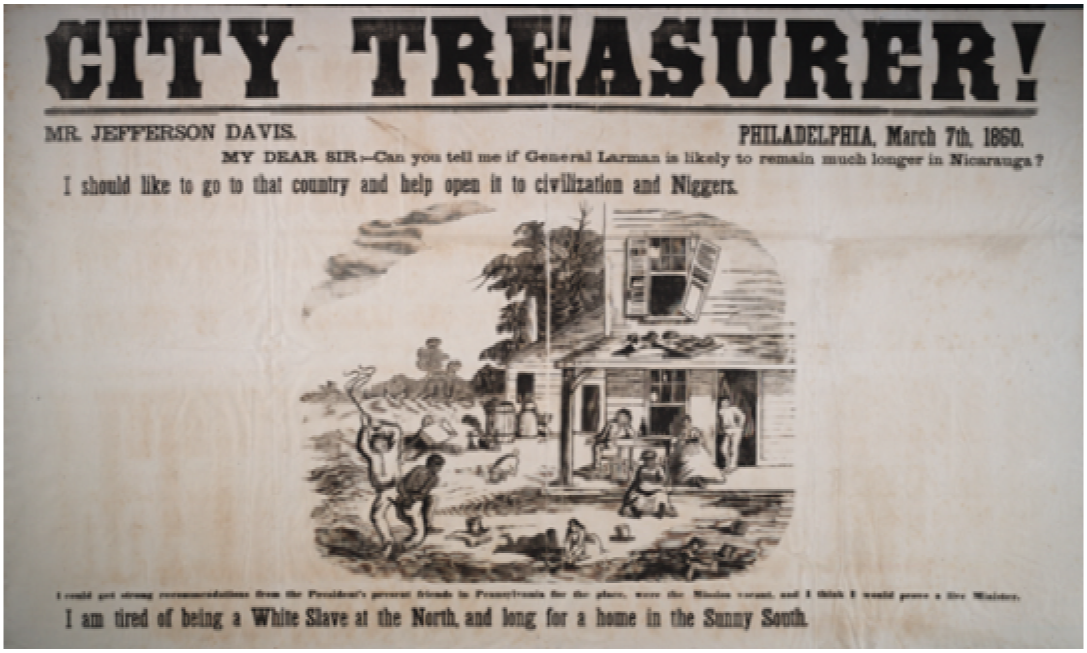
was a Negro woman taken into the buildig
and whipped today I dont know what
for and it will do no good to ask for
it is by chance if I could find out and
it is no use to say anything here for it
would only make a bad matter worse

In a final example, taken from the latter portions of the journal, Dunham comes out more explicitly in opposition to the brand of discipline practiced by slave drivers in Brazil: “An old man that takes care of the sheep was whipped tonight I dont know what for perhaps for some accident that he could not possibly help the German appears to be an ugly rascal and will whip when there is no occasion and for that matter I think there never is any need of whipping after they are grown up” (135). Perhaps not surprisingly, owing to his professional position, Dunham expresses his disapproval of the brutality that he witnesses in practical, economic terms, generally speaking. He perceives these methods as inefficient, counterproductive means for controlling the labor force that forms the foundation of Brazil’s agricultural economy. It is never clear to what extent genuine humanitarian concern lies behind his condemnations; nor is it certain if he is directing these critiques toward the practices of slaveholders in the U.S. South. Regardless of his personal politics, Dunham would have known that his contemporary readers, inundated with the slavery question, would read such connections into his text, so these passages can, at a minimum, be understood with that broader reality in mind.

Even if Dunham, in his journal, cannot necessarily be classified as an anti-slavery writer, his chronicling of the violence and exploitation associated with the slave system does evoke the abolitionist texts that helped to define antebellum U.S. literary culture. Douglass's *Narrative of the Life* and Jacobs' *Incidents in the Life*, for example, portray in stark detail the series of physical, mental, and sexual abuses suffered by themselves as well as their friends and family. These authors sought to make their experiences as real and immediate as possible in order to convince their readers of slavery's evils. Without that type of socio-political agenda behind his writings, Dunham does not approach the same level of detail found in Douglass and Jacobs; nonetheless, his observations contribute to an emerging portrait in the mid-nineteenth century of slavery as a cruel, demeaning, and unjust institution. One of the more striking moments from *A Journey to Brazil*, in which Dunham discovers copies of *Uncle Tom's Cabin* in Brazil, further motivates one to read the journal in relation to the anti-slavery literature of its day. "I find that Uncle Toms Cabin has got into Brazil and the people will read it," Dunham writes (168). This exciting passage provides at least two opportunities to a class in the process of studying Stowe's novel. A teacher could, of course, parallel the brutality of a character such as Simon Legree and the violent acts observed and recorded by Dunham. Yet another possibility would be to utilize this moment as evidence of *Uncle Tom's Cabin*'s global circulation, its worldwide impact on the issues of slavery and freedom. Paired with these classics of anti-slavery literature, Dunham's journal takes on massive import to the study of nineteenth-century cultural production.

City Treasurer [Slavery Poster], 1860

An oversize poster addressed to Jefferson Davis encouraging the exportation of U.S. slavery to Nicaragua.



CITY TREASURER!

MR. JEFFERSON DAVIS.

PHILADELPHIA, March 7th, 1860.

MY DEAR SIR:—Can you tell me if General Larman is likely to remain much longer in Nicaraugua?

I should like to go to that country and help open it to civilization and Niggers.

I could get strong recommendations from the President's present friends in Pennsylvania for the place, were the Mission vacant, and I think I would prove a live Minister.

I am tired of being a White Slave at the North, and long for a home in the Sunny South.

Another strategy for utilizing *Journey to Brazil* in the classroom would be as a vehicle for discussing slavery as an institution in other places within the Americas beyond the U.S. Dunham provides with some valuable firsthand observations of the inner workings of the Brazilian slave system. Brazil itself is, of course, an interesting case since it was the last country to officially abolish slavery, in 1888. More generally speaking, however, the journal will enable teachers to demonstrate the ways in which nineteenth-century slavery functioned as a transnational, hemispheric system. Dunham himself is a perfect example of how slavery in the Americas depended upon a transnational exchange of people, ideas, and technologies. Cultural critics have recently begun to explore in-depth the nature and ramifications of these dynamics, as can be seen in such studies as Matthew Guterl's *American Mediterranean: Southern Slaveholders in the Age of Emancipation* and the collection of essays edited by Deborah Cohn and Jon Smith, *Look Away! The U.S. South in New World Studies*. *Journey to Brazil* provides yet another important case study for drawing connections among the slaveholding practices of the U.S. South and those of other slaveholding societies throughout the hemisphere.

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The Experience of the Foreign in 19th-Century U.S. Travel Literature
This module considers strategies for teaching George Dunham's travel journal A Journey to Brazil in relation to other nineteenth-century U.S. travel narratives.

The Experience of the Foreign in 19th-Century U.S. Travel Literature

The travel narrative emerged as one of the most popular, if not the most popular, literary genre among nineteenth-century U.S. readers. Several critics, including Justin Edwards in his *Exotic Journeys: Exploring the Erotics of U.S. Travel Literature, 1840-1930*, have speculated on the type of socio-cultural work performed by these writings. Edwards and others have observed the travel narrative as a meaningful blend of entertainment and education. Detailed accounts of journeys to locales outside of the nation's boundaries fed the desire of readers for knowledge regarding the foreign and the exotic. Perceived differences in behavior, custom, and belief held a deep fascination for the nineteenth-century citizen, and, for many, the travel narrative provided the only vehicle for engaging that fascination. In addition to building a foundation of knowledge on foreign locales and populations, these narratives offered individual readers an opportunity to negotiate his/her position within the ever-shifting political landscape of the nation. With their authors/protagonists serving as a sort of proxy for those eager to experience their own encounter with the exotic, these writings encouraged their readers to think through their own national, racial, and gendered identities. The socializing function of the travel narrative, that which affirmed the place of its readers within the nation and subsequently the world, dovetailed nicely with the political project of Manifest Destiny and the westward expansion of the U.S. throughout the nineteenth century. Therefore, many of the most popular travel narratives, including Richard Henry Dana's *Two Years Before the Mast* (1840) and Mark Twain's *Roughing It* (1872), were those that centered around the western portions of what would eventually become the continental United States.

Reading George Dunham's *[missing_resource: http://hdl.handle.net/1911/9247]* (1853) - part of the [missing_resource: http://oaap.rice.edu/] *Two Years Before the Mast* and *Roughing It* will prove to be a highly rewarding endeavor for students of nineteenth-century U.S. culture and literature. Dunham has compiled a detailed, if somewhat haphazard, travelogue of his voyage on board the ship *Montpelier* and then his protracted stay in mid-nineteenth-century Brazil. Brazilian plantation owners brought him over in order to help modernize their plantation system through his knowledge of and experience with advanced agricultural technologies as well as the efficient organization of slave labor. If writers such as Dana and Twain provide us with insights into the role played by culture in the processes of territorial expansion that characterized the nineteenth-century U.S., then what may we learn from more obscure travel writings on what may be more unexpected locales? Dunham's journal (held at Rice University's Woodson Research Center) contains many of the same dynamics as those more studied travel narratives and will offer some useful points of comparison with those texts.

Map of the American Hemisphere, 1823

A portion of a map from Henry Tanner's *A New American Atlas* (1819-1823) that includes the U.S.'s Atlantic seaboard and Brazil.

Similar to other works of the time, Dunham foregrounds the exoticism of the foreign that readers found so tantalizing. Arriving in Brazil for the first time, he marvels at the sense of difference he feels between this place and the U.S.: "I first sett (sic) foot on land in Bahia in Brazill (sic) and looked around in astonishment it seemed like being transported to another planet more than being on this continent everything was new and wonderfull (sic) the buildings without any chimneys and covered with tiles the streets narrow and full of negroes a jabbering" (35). He goes on to write, in a similar vein, "the trees green and covered with tropical fruit and every thing else so different from home that was some time before I could realize that I was here" (36). The combination of foreign landscape, architecture, and peoples overwhelms Dunham, producing in him a sense of disorientation that was common among nineteenth-century author-travelers. At the same time, the presence of a black slave population would have been a point of keen interest, as well as identification, for many U.S. readers. Dunham no doubt knew that readers would be projecting their own experiences with slavery onto these moments within his journal, exciting curiosity about his experiences and debate about the relative merits and practices of the slave system. Many critics, such as Amy Kaplan in *The Anarchy of Empire in the Making of U.S. Culture*, have written that it is this blurring of the domestic and the foreign, of home and abroad, that is central to the socio-cultural operations of travel literature.

Later in the journal, after he has spent some time in Brazil, Dunham engages in sharp criticisms of the practical workings of this society, another familiar trope from the travel narrative. Manifestations of his frustration take on nationalist overtones in statements such as, "I am satisfied it is of no use to make any calculation on anything in this country where it depends upon the people to perform it" (see Figure 2 [a]); or, "they say that whenever a person has the consumption in this country if they have the fever they die immediately" (see Figure 2 [b]). The latter pronouncement portends the death of the American traveler owing to the relative medical backwardness of foreign lands. The implied superiority of U.S. knowledges and practices pervades much travel literature of this time, including those aforementioned texts concerning the burgeoning western frontier. As scholars have noted, these articulated attitudes toward the western territories invited, or perhaps even demanded, the civilizing influence emblematized by competent white Americans.

A Journey to Brazil, 1853

Excerpts from the original manuscript of George Dunham's travel journal.

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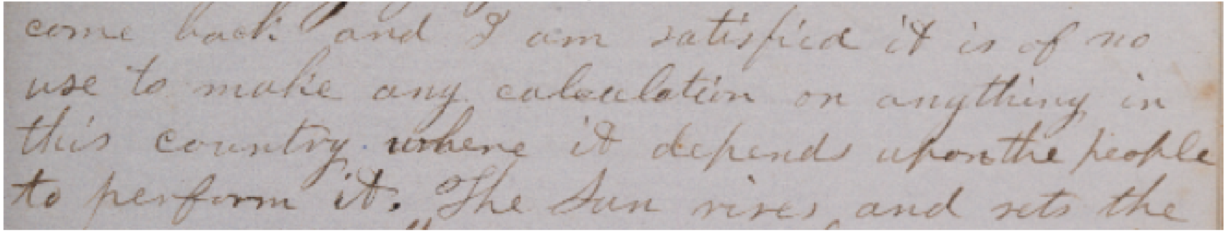
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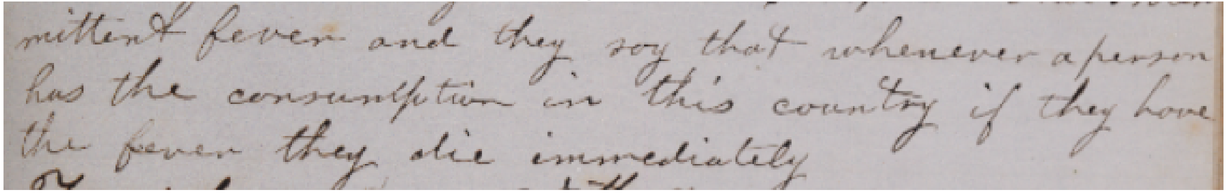
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In designing a lesson plan around *Journey to Brazil* and nineteenth-century U.S. travel narratives, an instructor may also want to include a representative of those works dedicated to travel in the Holy Land. Texts that focused on journeys to Palestine and its surrounding territories enjoyed a massive degree of popularity among American readers, particularly in the latter half of the nineteenth century. Some of the more popular of these works included Twain’s *The Innocents Abroad* (1869) and W. M. Thomson’s *The Land and the Book* (1870), an illustrated travelogue of the Holy Land. In his critical study *American Palestine: Melville, Twain, and the Holy Land Mania*, Hilton Obenzinger argues that since many Americans regarded themselves as a chosen people, anointed by God to carry out a revivalist mission in this new nation, written works on the Holy Land held for them a special interest. Obenzinger insists, and many critics agree with him, that even if Holy Land literature was not the most popular form of travel narrative (though it may have been), then it was certainly the most ideologically significant. Dunham’s journal forces us to at least re-think that assertion. The 1853 publication of the journal shows an interest on the part of the American reading public in travel, both real and imagined, to places throughout the Americas as well. Richard Henry Dana, the same man who famously wrote on the western frontier, would chronicle his travels in the Caribbean in an 1859 book entitled *To Cuba and Back: A Vacation Voyage*.

John O’Sullivan, accredited with the coining of the term “Manifest Destiny,” would in later years become a staunch advocate for the annexation of Cuba to the U.S. Finally, *A Journey to Brazil* provides yet another piece of compelling evidence that the hemisphere as a whole played a role in the U.S. imagination equal to that of both the western frontier and the Holy Land.

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